THE VELOCITY GRADIENT IN THE PSEUDO-PHOTOSPHERE OF THE PECULIAR SUPERGIANT HD 101584

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Abstract

In this paper preliminary results are presented based on a study of the low and high resolution ultraviolet spectrum of the peculiar supergiant (post-AGB star) HD 101584. By a comparison of the low resolution spectrum ($1200-3200$ Å) with standard stars, the star is classified as an A7I, indicating an effective temperature of 8150 K, where literature quotes spectral type F0I. The Doppler shift of the FeII absorption lines in the high resolution spectrum ($2500-3000$ Å) show a relation with the line optical depth. This suggests an expanding accelerating wind, c.q. pseudo-photosphere. The relation is extended by a factor 10^5 in optical depth by using available data from optical HeI and NI lines. The relation suggests that the radial heliocentric velocity of the star is at least 54.5 km s^{-1}. From the Hα line a velocity of 96 km s^{-1} is measured for the terminal velocity of the wind.

1 Introduction

The star HD 101584 (b = 6^o) is classified as a 7.01 visual magnitude F0Iape with $(\mathrm{B-V}) = +0.39$ (Hoffleit 1983), indicating an effective temperature of 7700 K , log g = 1.7 , and thus $(\mathrm{B-V})_0 = 0.17$ (Landolt-Börnstein 1982). Far- and near-infrared photometry reveals a strong infrared source at the position of the star (Humphreys & Ney 1974; Parthasarathy & Pottasch 1986). Molecular line observations show bipolar outflow for the OH maser (te Lintel Hekkert et al. 1992) and a very complex structure for the CO($J = 1 \rightarrow 0$) transition (Trams et al. 1990; Loup et al. 1990; van der Veen et al. 1992). The molecular line emission in OH and CO is normally discussed in terms of evolved stars, and fits the idea that HD 101584 is a post-AGB star.

The first to classify the star HD 101584 as a post-AGB star were Parthasarathy & Pottasch (1986). Their conclusion was based on the strong infrared excess of the star which seems to be due to a large amount of dust around the star. An extensive study by Trams et al. (1991) shows the resemblance of the infrared excess of HD 101584 with other known post-AGB stars. It is now reasonably well established that HD 101584 is a post-AGB star.

2 The ultraviolet spectrum

2.1 The low resolution IUE spectrum

The low resolution IUE spectra (9AA) of HD 101584, a A7I and a F0I standard star are shown in figure 1. Before fitting the ultraviolet energy distribution to a standard star the spectrum was smoothed over 12.6 Å and corrected for interstellar and circumstellar

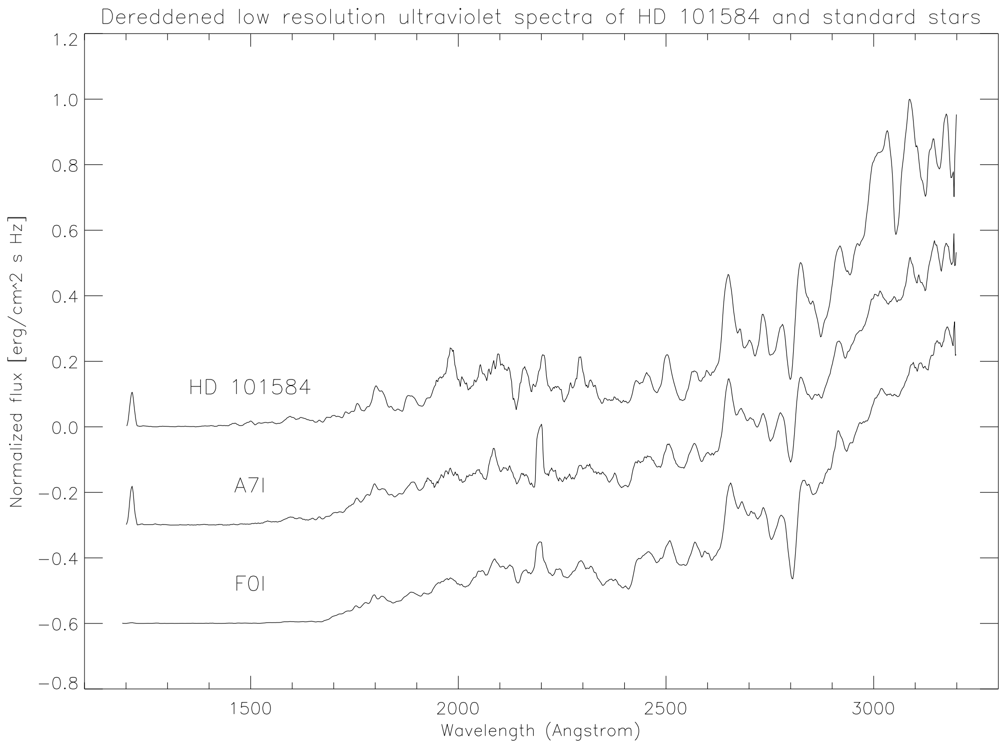

Figure 1: The low resolution IUE spectrum of HD 101584 (upper), a standard A7I star (middle), and a standard F0I star (lower). The spectra are smoothed over 12.6 Å, normalized, and dereddened

extinction (Mathis 1990) using a colour excess, $E(B-V) = 0.27$, derived for spectral type A7I.

The low resolution ultraviolet spectrum was best fitted to the standard A7I star, HD14873. An even better fit is possible if also an A6I star would be available in the reference atlas (Heck et al. 1984). The spectrum of HD 101584 shows no flux lower then 1400 Å and can therefore not be fitted with a spectrum of a star of spectral type A5I or hotter.

By comparing the spectrum of HD 101584 with the standard F0I star, α Lep, an excess of flux for the program star between 1400 and 1700 Å indicates a higher temperature of the star. The slope of the continuum of the spectrum confirms the supergiant nature of the star. The data on the spectrum of HD 101584 and on the two reference stars is in table 1.

2.2 the high resolution IUE spectrum

In an extensive study of the high resolution (0.3 Å) IUE spectrum of HD 101584 a large number of absorption features between 2500 and 3000 Å has been identified (Bakker 1994). The main conclusions from this work are that the spectrum of HD 101584 has in principle the same absorption features as the F0 supergiant, α Lep, but the lines are intrinsically broader and the lines are asymmetric in shape. This study limits itself to the measured radial velocities of the absorption features as derived from the measured Doppler shift of the core of the absorption profile.

Table 1: Data on the low resolution spectra

HD number	Name	Spectral type	E(B-V)	Normalized on [erg cm^{-2} s Hz]
HD 101584		A7I	0.27	4.1 10^{-23}
HD 36673	α Lep	F0I	0.04	6.0 10^{-22}
HD 148743		A7I	0.25	2.8 10^{-23}

Table 2: Stellar parameters for HD 101584 based on literature and on the low resolution ultraviolet IUE spectra studied in this work

Work	Spectral Type	Effective Temperature	log g	$(B-V)_0$	$E(B-V)$
Hoffleit 1983	F0I	7700	1.7	+0.17	0.22
This study	A7I	8150	1.9	+0.12	0.27

T_{eff}, log g, and $(B-V)_o$ from Landolt-Börnstein (1982) and are based on the given spectral type.

In probing the photosphere of a star the line optical depth is a measure for the depth in the photosphere seen. The stronger the optical depth τ the more outside layers of the photosphere will be probed. The range in optical depth from the ultraviolet spectrum is limited to about a factor 10^4. By incorporating some of the available optical data, which are from much weaker lines, the deeper layers of the photosphere can be probed as well and the relation can be extended over a much wider range of τ by a factor of 10^5 to 10^9. There are however two assumptions in making the relation valid for a larger range of τ. The first is solar abundance ratios, and that NI, HeI, and FeII are the dominant ionization stages of these elements in the stellar wind (or pseudo-photosphere). The second is that the effective temperature derived from the energy distribution in the ultraviolet represents the real temperature of the gas. If the first assumption is violated, the separate elements will shift horizontally in the fig. 2. If the second assumption is violated, the relation within FeII will change, and there will occur a small horizontal shift between the different elements. The data on FeII, NI, HeI and Hα will be published in a separate paper which is in preparation (Bakker 1995).

Figure 2 shows the relation between the logarithm of the strength of an absorption line and the heliocentric radial velocity measured for that line. The crosses are the FeII lines from the ultraviolet spectrum, the triangle the optical nitrogen line (8680.24 Å), and the asterisk the optical helium line (5875.618 Å).

$$V_{helio}(\mathrm{FeII}) = 49.1 - 5.1 \times \left[\log\ \mathrm{N} + \log\ \mathrm{gf} - \frac{5040\chi}{\mathrm{T_{eff}}}\right] \left[km\ s^{-1}\right] \quad (1)$$

A first order approximation of the relation for the FeII line is given by eq. 1. The reason that the HeI and NI line are not used for this first order approximation is that is seems logical to assume a constant velocity for weak lines. These lines are formed in the deeper layers of the photosphere and are therefore least affected by the unknown force which accelerates the pseudo-photosphere outwards. The dashed line in fig. 2 shows the first order approximation based on only the FeII lines. It is surprising to see that the HeI and NI line fit this relation almost perfectly.

Table 3: Main parameters of the chemical elements used in probing the pseudo-photosphere

Element	Solar Abundance log N	Ion	Ionization Energy (eV)	Excitation Energy (eV)
He	10.93	HeI	24.587	20.87
N	7.96	NI	14.534	10.29
Fe	7.60	FeII	16.16	7.870 $\rightarrow$ 4.48

Solar Abundance, and ionization energies are from Allen (1985).

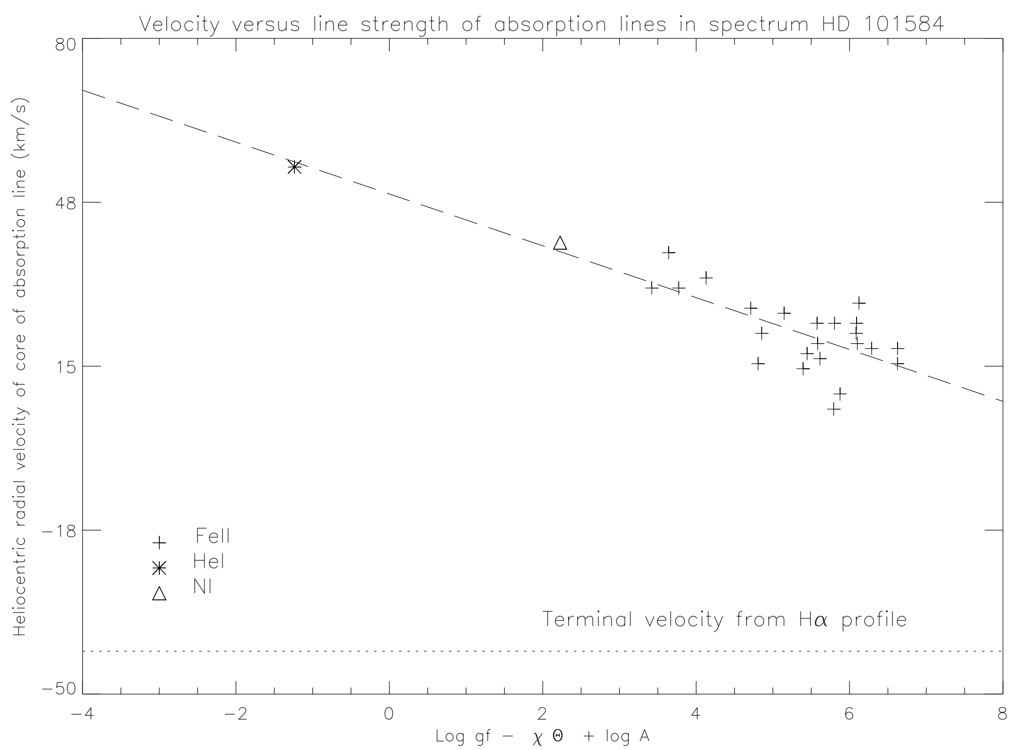

Figure 2: Relation between the strength of an absorption line and the radial velocity measured for that line, indicating that we are looking at an accelerating expanding wind. The dashed line is a first order fit based on the FeII lines. The HeI and NI line seem to fit this relation exceptionally well. Where θ is $5040/T_{\rm eff}$, χ is the excitation potential of the lower level of the transition, and A is the abundance relative to H by number

3 Terminal velocity of the stellar wind

An upper limit on the maximum out streaming velocity (a lower limit on the blue shift of a line) is given by the absorption part of the Hα line profile. The edge of the Hα line profile is pretty steep, implying that hydrogen column density at that velocity does not slowly decrease due to expansion (and thus dilution) of the gas, but rather that the edge in the profile is due to hydrogen at the terminal velocity of the stellar wind. The maximum out streaming velocity is 120 km s^{-1}, and the out-streaming velocity derived from the Doppler shift of the core of the absorption profile is 96 km s^{-1}. The latter velocity is the terminal velocity of the wind. The first is the net velocity maximum due to turbulent motion in the wind and its expansion. If we assume that the velocity of the star is best represented by the velocity of the HeI line, a minimum heliocentric velocity of -41 km s^{-1} is expected. The dotted line in fig. 2 represents the terminal velocity of the wind as determined from the Hα profile.

4 Discussion

The data in the literature concerning the radial velocity of HD 101584 is very confusing. It's variations are not well understood and is a fruitful base for wild speculations. From this study a little light is shed on these variations. The relation as shown in figure 2 reveals that variations in radial velocity within one spectrum (FeII lines) can be understood in terms of an expanding accelerating photosphere or wind. In the following discussion this line absorbing region will be called pseudo-photosphere. This relation can be extended to lower optical depth by incorporating the helium (5875.618 Å) and nitrogen (8680.24 Å) optical absorption lines. That this relation holds for helium suggests that this line is from the same star and not from a yet unseen hot companion star. To produce a helium absorption line the star has to be much hotter than spectral type A7I, probably even a B-type star. This contradicts the fact that the low resolution ultraviolet spectrum is best fitted with a A7I reference star

Although the relation does not seem to go to a constant velocity for weaker lines (HeI and NI) is seems reasonable to assume that the velocity for the HeI line is the stellar velocity. By monitoring the velocity of the HeI absorption line it should be possible to make a statement about the binary nature of the star. Radial velocity measurements of stronger lines do not only have a contribution of the radial velocity of the star due to binarity (if this would be the case), but will also have a contribution from the pseudo-photosphere. These two contributions will be very hard to disentangle. A maximum velocity of the out streaming wind as determined from the Hα profile is 96 km s^{-1}. This means that velocities of absorption lines are to be expected in the range between -41 km s^{-1} and 54.5 km s^{-1}.

Table 4 summarizes the stellar parameters of HD 101584 as determined in this study from ultraviolet spectra.

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Table 4: Improved data on HD 101584

Ultraviolet spectral type	A7I
Effective temperature	8150 K
E(B − V)	0.27
Heliocentric velocity of star	54.5 km s^{-1}
Terminal velocity of wind	96 km s^{-1}
Maximum helio. velocity expected	54.5 km s^{-1}
Minimum helio. velocity expected	−41 km s^{-1}

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